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ECONOMICAL DRIVE FOR LARGE TUBE MILLS
BY MEANS OF PLANETARY GEARS

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ECONOMICAL DRIVE FOR LARGE TUBE MILLS BY MEANS OF PLANETARY GEARS

by W. Ackle, Zuerich

1. Introduction

When the managers responsible for cement operations encounter an unfamiliar technical element, there generally is a good deal of skepticism. This is understandable, especially when one considers:

- The operational security of a large production installation, as it would be directly affected.
- The technical particulars may be quite unfamiliar in concept to the builder of the cement installation.

and

- The manager may have had bad experiences with other similar devices, which may indeed have the same name, but with totally different quality and construction principles.

But if a technical solution has proven itself in a certain practical application, there is no doubt that it will attract interest among builders of cement installations. It will tend to be remembered over the period of years while it is accumulating an operational history, and while the state of its technical development is being improved.

These conditions are met for the Maag central drive with planetary gears for large tube ball mills.

Among the properties of this construction arrangement which are attracting favorable attention is the superior operational safety. But increasingly important as well is the economy possible in an installation which requires great amounts of energy. It is not only the energy requirement itself in a large installation which causes significant costs; even more important is the optimal use

of the total available quantity of energy. This must be utilized in the cement production process in the most prudent manner possible.

The purpose of the present article is to furnish a status report dealing with present conditions, and to deal with a number of specific points in detail.

The problems dealt with here constitute an expansion of results already published.¹⁾

2. Extent of Experience with Planetary Gears

Figures 1 and 2 show the range of experience on which these remarks are based.

The total transfer capacity of Maag planetary gears contracted for by the Cement industry up to the end of 1974 comes to about 150,000 HP, and this capacity is divided into 32 drive units. The distribution of the drive units into the various capacity ranges is represented by Figure 2.

Counting the output of about 70% of the planetary gears referred to above, about 350,000 operational hours were logged by the end of 1974. This corresponds to about 900 million tons of cement.

The climatic conditions in which these drives were used range from moderate to tropical.

3. Drive Systems

The basic conception chosen for the planetary gear and the system of axially coupled machine groups (Figure 3) has proven

- 1) Ackle, W., Planetary Gears for the Driving of Large Tube Ball mills, (Translation of Planetengetriebe zum Antrieb von grossen Rohrkugelmuehlen,) Zement-Kalk-Gips 22 (1969), 125.

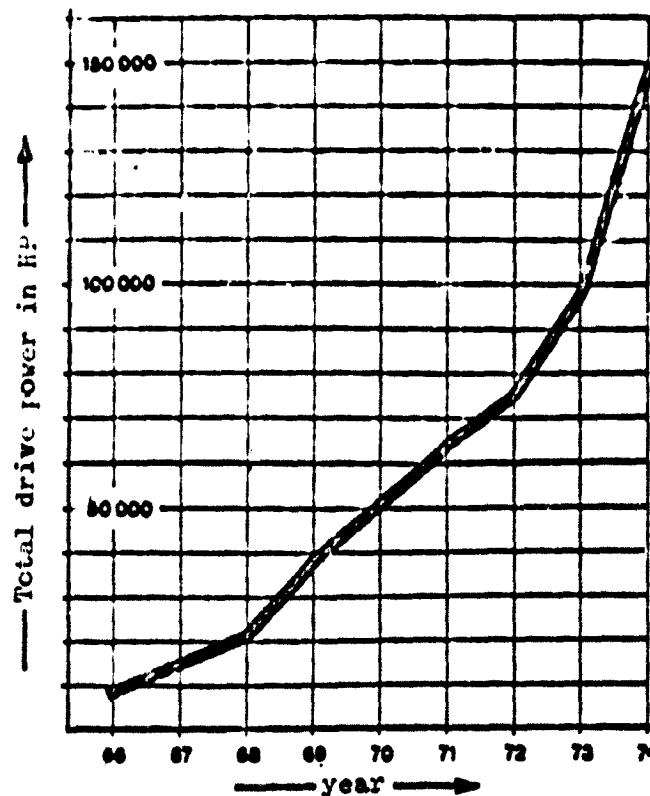


Figure 1: Total capacity of Maag planetary gears being used in the cement industry.

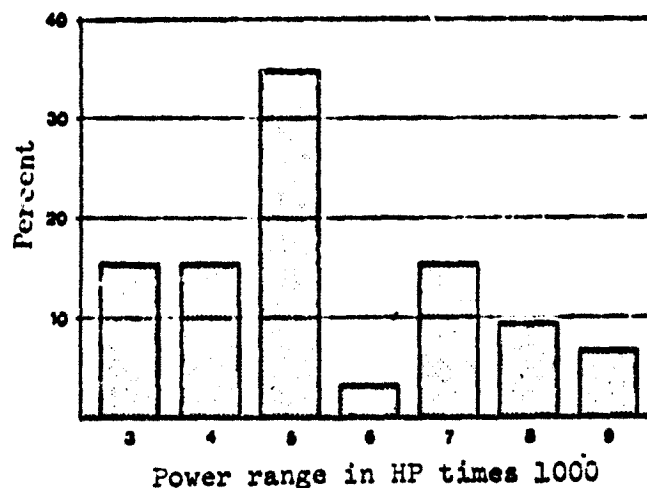


Figure 2: Capacity range of the Maag planetary gears contracted for by the cement industry up to 1974.

itself in practice. During the time of operation, refinements leading to increased safety or simplification were carried out.

Double planetary gears can be manufactured with a transfer capacity of up to 10,000 kW.

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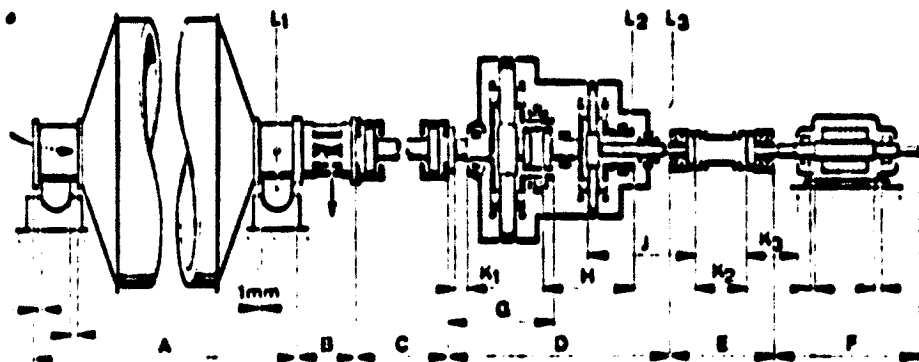


Figure 3: Axially coupled machine group.

- A Mill
- B Discharge tap
- C Jaw clutch coupling with torsion shaft and axial play limiter
- D Planetary gear
- E Jaw clutch coupling with intermediate piece and axial play limiter
- F Electro motor
- G Planetary support 2nd Stage
- H Planetary support 1st stage
- I Sun pinion 1st stage
- K1 Mounting control distance, planetary gear
- K2 Mounting control distance between motor and gear
- K3 Mounting control distance, electromotor

Three clearly differentiated systems are to be distinguished, with reference to bearings, and temperature deformation:

Axially-fixed bearings	Subordinate machine element
L1	A, B, C, G
L2	H
L3	J, E, F

Uncontrollable axial pressures resulting from thermal deformation are avoided in each of the three systems.

Figure 4 shows a mill with the entire drive group, consisting of:

planetary gear, electromotor, auxiliary drive, and lubrication installation.

It is advantageous to locate the lubrication oil unit directly beneath the gear in a closeable, dust-free room. When the instrumentation board is fastened to the concrete foundation wall, it is easily seen, it is protected from damage, and is easily accessible.

Figure 5 shows the simple technical gear construction.

In each stage, a system-determined, equalized distribution of moment of inertia is achieved.

The small foot-supporting surfaces, which bear a section of the two-way central drive, prevent operation where there would be only tip contact of the gear teeth, which might result from housing deformation caused by non-planar installation surfaces.

The perpendicular teeth permit telescopic axial sliding into one another in case of temperature deformation, without damaging housing deformation forces being generated.

4. Operational Experiences.

4.1 Tooth flanks after full-load operation.

Experience with individually hardened, corrected, and ground tooth arrays can be summarized as follows:

Spare toothed gear parts were not needed in any case studied. Even after 6 years of full-load operation, teeth still exhibited an essentially new condition. Grinding marks on the flanks

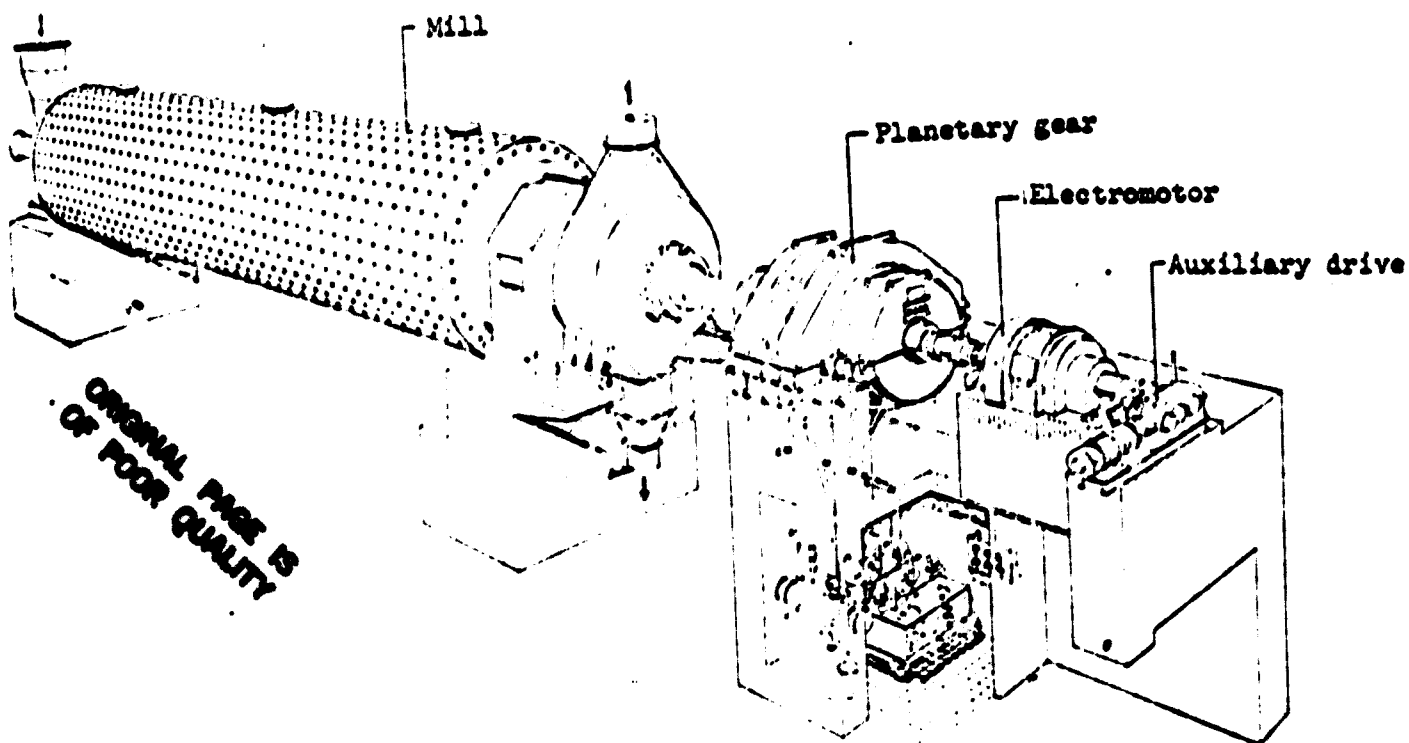


Figure 4: Tube mill with planetary gear - central drive.

were for the most part still visible. The wide-spread misconception that the efficiency of the gears decreases with the number of hours of operation, was effectively refuted by this determination.

In addition, the tooth flank upper surfaces observed in the same drive, in three jaw clutch couplings, were in very satisfactory condition.

4.2 Planetary axles after full-load operation

Figure 6 shows planetary axles after an operational time of 4 years. The chafing marks on their bearing metal surface indicated essentially new condition.

In central bearings with reduced loads, the chafing picture is even more pronounced.

The chosen type of bearing (that is, pressurized oil lubricated)

fully met the expectations placed upon it.

In a prototype gear, planetary axles were used which possessed fastened bearing metal surfaces. They have not proven themselves reliable.

When the bearing damage thus appeared, and since a spare bearing was not available, the operation was interrupted for a very short time, while the babbit metal was replaced.

As a result of that bearing failure, there was, however, no damage suffered by the teeth. This could not be expected of roller bearings.

4.3 Unusual Load Cases

Small alterations in the electrical starting system led in one case to an unsymmetrical turning field, and corresponding fluctuations in moment of inertia in extraordinary magnitude. The gear accepted this unusual demand without negative side-effects.

4.4 Drive separated from the mill

In the cases of mill disassembly, repair, or replacement of end-wall pieces, the principle of a free-standing mill tube was seen to be advantageous and time-saving. Then the drive group did not need to be moved in such kinds of work.

4.5 Unusual Mill Temperatures

The temperature of the mill can be substantially increased by, for example, failure of the control parts, and by injection with hot clinker. The resultant machine deformations can easily be dealt with by the systems described.

4.6 Monitoring of the Gear

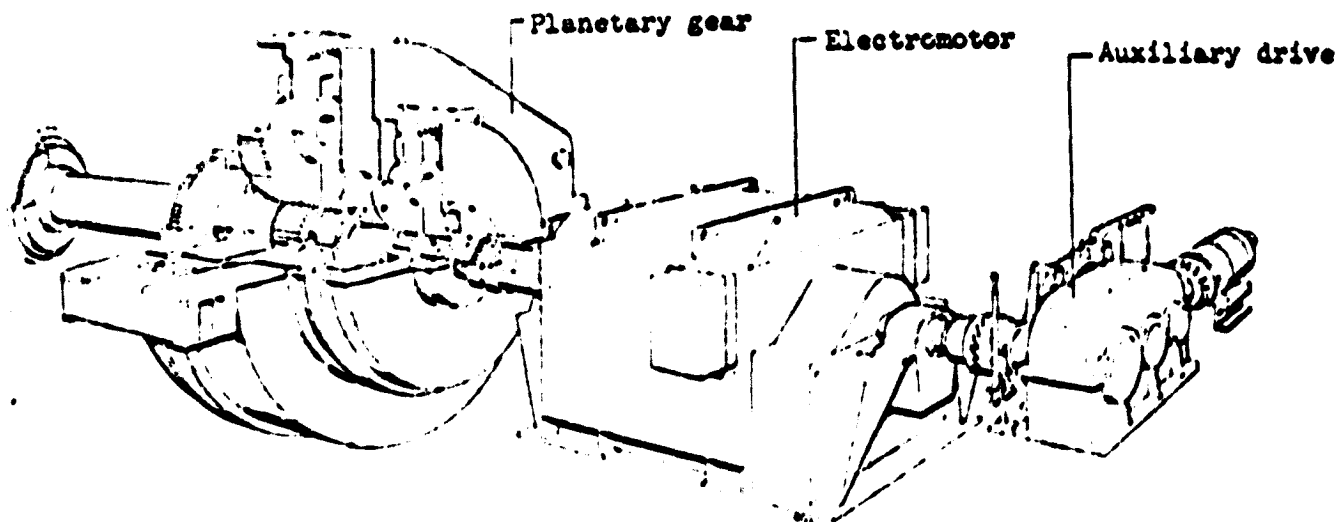


Figure 5: Planetary gear with electromotor and auxiliary drive.

The function of the apparatus should regularly be checked by means of a few simple instruments, and the parameters should be fixed in writing. Avoidable extensions of technical apparatus should be eliminated.

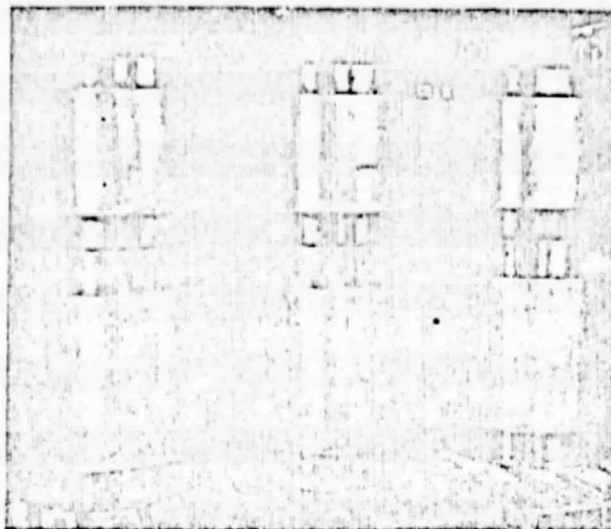
Experience has shown that a small number of carefully observed instruments, and monitored values are fully sufficient for optimum conditions.

4.7 Electromotor without axial bearings

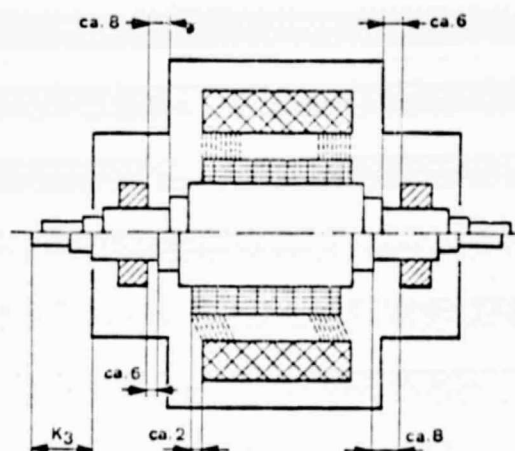
The minimal axial distances between motor bearings and shaft joint are represented by the values in Figure 7. It is necessary to differentiate between "cold status at mounting" and "warm status in operation".

In making axial adjustments during machine installation, it is important to consider the axial length variation caused by temperature deformation. The rotor must lie axially in the magnetic field of the motor during operation.

Figure 6: Planetary axles after 4 years full-load operation.



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Above: Shaft position at operating temperature

Below: Shaft position cold at mounting

Figure 7: Electromotor without axial bearing

(Numerical figures in mm)

The control distance K3 (Figure 7) to be maintained during installation should be engraved by the motor manufacturer in a clearly visible location.

The asynchronous electromotor, attached to a medium voltage network of 6 to 11 kV, has a number of important advantages over a synchronous machine. Among these are a high degree of efficiency, a reasonable power factor, as well as small expense for upkeep and lower incidence of damage. Further, there are no undeterminate risks of, for example, network disrupting influences, as would be the case in frequency controlled, slow running synchronous motors. Requirements of the energy supplier cancel each other out in these cost considerations. It is important to consider in the planning stages the usual compensation of reactive current, as well as the utilization of periods of lower current demand, such as nights and weekends.

In the case of either usual or unexpected uses of the mill installation, no additional forces arise from the electromotor, and no forces from the motor influence the operational security of the mill.

5. Gear Vibrations and Running Noise

Gear vibrations are in any case very minimal.

Measurements provided values which, in the case of full load, were substantially below the VDI standard.

If the installation is in the vicinity of housing developments, the usual requirements must be met. Among these must be considered ground conditions, and foundations must be designed in an appropriate way.

The vibration behavior of the electromotor should be considered in a similar way.

The noise situation must be considered in conjunction with all component noise sources (mill, gear, motor, ventilator, factory

noises, etc.).

Generally, the drive group and the mill are placed in a closed room. The gear room should be sound-isolated against noise emission into the outside in the same way the mill room is.

The practice of locating the entire milling operation within one hermetically sealed mill building has proven to be acceptable.

Special steps to ensure the low noise emission level of the planetary gear were not previously necessary, since the noise of the mill was greater than that of the corresponding gears. Furthermore, operational safety is naturally more important than great quiet in running operation.

Nevertheless, design alterations were carried out which provided good possibilities for noise reduction, especially in the first stage.

Although the grinding noise of the mill can hardly be altered, the entire noise output of the installation can be reduced by the improvement of the noise characteristics of individual elements. This is true since not only the intensity, but also the load distribution is important.

The following measured values in a cement grinding installation support this contention:

In an exposed measuring point outside a cement factory, the noise level in the dominant Terz bands increased by 6.4 dB in the 400 Hz band and 9.9 dB in the 500 Hz band when the ventilator was turned on; when the entire cement mill with planetary gear was also turned on, there was only a further level increase of 0.4 and 0.8 dB respectively.

In another measurement point, the noise level came to 45.5 dB (A) without ball mill, without planetary gear, and without ventilator - 48.6 dB (A) with operating ventilator, and 48.8 dB (A) with operating ball mill with planetary gear.

6. Working cycle - Interval rotation

In order to load the network more evenly, large milling installations operate during the night. Operating interruptions are located in the times of peak current consumption. If the installation cannot be operated in continual fashion, the mill must be started each 24 hours from either a partial or fully cooled condition. Tumbling action, and changes in shape which arise, take place until the operating temperature is achieved.

Positional displacements of the mill connection flanges during the warm-up time are compensated for by the jaw clutch coupling system with intermediate shaft. Thus no unacceptable effect on the drive elements arises. As a result there is no need for interval rotation for the avoidance of mill deformation during the cooling process.

Nevertheless, after the mill is turned off, it can be turned by 180° in predetermined time intervals by the use of the auxiliary drive.

When doing this, it is important to assure that the mill is always started from the equilibrium position.

7. Lubrication Installation and Monitoring

The oil system (Figure 4) has two chief duties to perform:

1. Lubrication of the bearings and gear teeth
2. Regulation of the thermal condition of the planetary gear

The installation consists of:
Oil tank, 2 oil pump groups (one reserve), oil filter, oil cooler,
oil heater, monitoring instruments.

Generally, an oil pressure in front of the gear of 3 to 6 kp/cm^2 is used. A compound EP lubricating oil with a viscosity of 18 to 22° E (140 to 170 cSt) at 50°C is used.

The oil tank is fitted with autonomously functioning instrumentation and temperature regulation. The electrical heating works through temperature-resistant, thin thermal transfer oil. The specific surface loading of the heating element comes to about 0.75 W/cm^2 . The thermal transfer to the lubricating oil is carried out by an intermediate wall. In this way, any reduction of the lubricating effect of the oil caused by localized overheating or burning is avoided.

As a rule, a heating capacity of 12 kW is provided.

The monitoring instrumentation for the oil entering or leaving the gear, effects the drive elements of the installation directly. In this way signals are given, or operation is interrupted.

Basically, the following are watched:

Before entrance into the gear

Oil pressure

manometer

reading

manostat

switching function

Before entrance and after exit from the gear

Oil temperature

thermometer

reading

thermostat

switching function

If a starting blockage or an operating interruption is generated, it must be possible to determine in the control room, just which instrument has been responsible. The control current should be interrupted by reporting of that instrument.

The regulation of the thermal condition is carried out according to the temperature of the environment by either heating or cooling. The lubricating oil serves as the thermal conductor.

The drive installation is thus largely independent of environmental temperature fluctuations.

Depending on the water temperature differential in the oil cooling, the cooling water quantities listed in Figure 8 are generally required. For this purpose, the water inlet temperature should lie below 35°C.

The correct gear temperature is necessary for a high degree of efficiency and for a high degree of safety.

Figure 9 shows the typical temperature history during the starting process at low surrounding temperatures.

8. Transportation

Planetary gears are transported either as assembled units, or -- in larger transfer capacities -- in two gear stages.

The weight of the first gear stage comes to about 20 or 24% of the entire gear weight.

Transportation by road is possible up to a transfer capacity of about 6,000 HP.

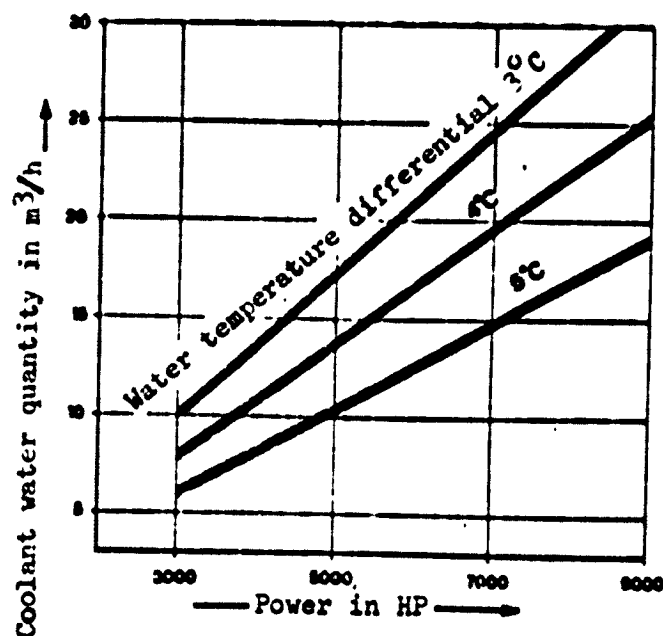


Figure 8: Required quantity of coolant water dependent on capacity and coolant water temperature differential.

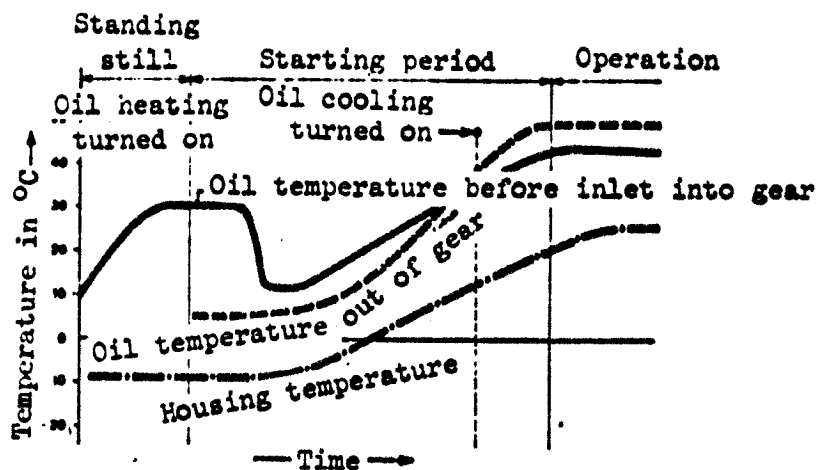


Figure 9: Temperature behavior with a cold start of the drive installation.

Figure 10 shows a gear for an 8,500 HP transfer capacity unit during transportation by road.

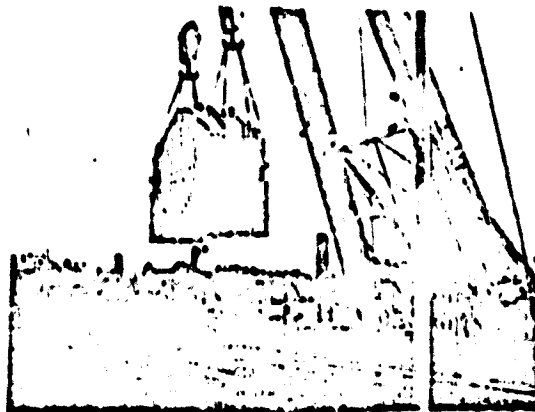


Figure 10: Second gear stage of a 8500 HP planetary gear during transportation on roads.

8.1 Means of Lifting and Mounting

Lifting procedures, for example onto the road transport vehicle, are generally carried out by means of a mobile crane.

Within the machine building, on the other hand, lifting is better accomplished by means of a stationary crane, the lifting capacity of which corresponds to the weight of the first gear stage.

By using this crane, it is possible in emergency completely to disassemble the planetary gear, should it become necessary.

The necessary useful load capacity of the crane and crane hooks can be roughly determined by use of Table 1.

In exceptional cases, the drive can be mounted without the use of the crane, by utilizing simple equipment. This does take substantially more time, however.

Table 1

**Crane Useful Load and Height of Crane Hook for
Maag Mill Planetary Gears**

N n (min ⁻¹)	Original installation		Completed disassembly inside the installation	
	Mobile crane	Crane hook over middle of the gear	Stationary crane	Crane hook over middle of the gear
	t	m	t	m
110	12	2.5	7	2.1
160	24	2.7	9	2.3
220	33	3.0	10	2.5
280	34	3.3	12	2.7
320	48	3.5	13	2.9
390	58	3.6	18	3.0
500	69	4.2	21	3.3
560	80	4.7	25	3.6
640	100	5.1	30	3.8
750	145	5.6	40	4.1

Mounting and adjusting the drive group can be accomplished in 3 to 4 weeks, if the concrete foundations are capable of bearing the weight, and if the crane and connecting equipment are available. One or two gear specialists and three or four helping personnel are needed.

9. Degree of Efficiency -- Economy

Mill planetary gears belong to the group of slow running gears with part circular speeds of under 10 to 15 m/s. They behave differently than the fast running gears with part circular speeds of 100 m/s and more.

In toothed gears, losses occur in the teeth themselves, and in the bearings.

Case hardened and precision ground teeth generate less friction losses as, for example, unhardened and unground teeth with correspondingly larger tooth width.

In the case of slow running central gears (double branching gears and planetary gears) efficiency measurements are carried out by the following method:

1. The gear is measured on the test stand without any load, so that loss is measured both directly and indirectly.
2. The indirect measurement method, calibrated in this way, is then utilized in the installation under load.

9.1 Unloaded running measurements on the Test Stand

The direct measurement is carried out with calibrated torsion-dynamometer between the electromotor and the gear. The reported value corresponds to the total unloaded running loss.

In the indirect measurement, the inlet- and outlet temperatures of the coolant oil are determined by precision mercury thermometers, and the oil quantity is determined by a calibrated volume measure.

For the measurement of the impelling pressure of the coolant oil pump, calibrated manometers are used.

The characteristic of the lubricant oil pump is measured on a special test stand.

The heat carried off by the coolant oil is calculated by:

$$P_W = Q_{oil} \cdot \rho_{oil} \cdot c_p \cdot (t_{oil}^{427} - t_{oil}^{00.75}) \quad (PS)$$

P_w = lost power in HP

Q_{oil} = coolant oil quantity in dm^3/min .

γ_{oil} = specific gravity of coolant oil at operating temperature in kp/dm^3 .

c_p = specific heat of coolant oil at operating temperature in $kcal/kp \times ^\circ C$

Δt_{oil} = oil temperature difference in $^\circ C$

The warm housing gives off heat to the room. The room temperature is measured in various locations at a distance of 1 m. In characteristic locations, the temperature of the housing surface is measured.

The heat given off to the room is calculated by:

$$P_R = \frac{S \cdot \Delta t \cdot A}{730} \quad (HP)$$

The symbols here mean:

P_R = heat given off to the room in HP

S = thermal transfer coefficient in $Watt/m^2 \times ^\circ C$

A = Thermal transfer surface in m^2

Δt = temperature difference in $^\circ C$

If the total loss measured by the torsions dynamometer is denoted by P_T , the following equation applies:

$$P_T = P_w + P_R$$

The value S comes from the power balance at a state of rest. It has been demonstrated that this corresponds well with the values in the literature.

9.2 Full-load measurements in the installation:

In the full-load measurements, the heat given off in the cooling oil is measured in the same way as in the tests on the test stand (cf. Section 9.1). The same measurement apparatus is used for this. The critical values here are those which were determined at identical machine temperature at a state of rest.

Room temperatures and housing upper surface temperatures are measured at the same locations as in the unloaded test. The lubricant oil pump output P_p is derived from the pump characteristic. The sum of all losses P_v is composed of:

$$P_v = P_w + P_R + P_f$$

The power P_K given up by the coupling between gear and mill is derived from the electrically measured motor power, reduced by the gear loss.

The gear efficiency η is then calculated as follows:

$$\eta = \frac{P_K}{P_K + P_v} \cdot 100 (\%)$$

The full-load gear efficiency measured in this manner for such central gears, lies between 98.6 and 98.8%.

The tests show that the thermal loss P_R given off to the room comes to about 12% of the total loss.

The larger portion of the loss in full-load operation comes in the teeth, while losses in the bearings are substantially smaller.

The unloaded losses measured come for the most part in the bearings. In full-load operation the bearing losses suffer only an insignificant increase.

9.3 Efficiency of the Drive Installation

In order to generate comparisons between various drive solutions and to be able to judge total losses, the efficiency of the drive motor must be included.

In Europe, mostly asynchronous motors are used for the driving of tube mills. The kind of full-load losses such motors have is shown by the example of a tube mill driven by a 6.4 MW motor.

- full load loss of the asynchronous electromotor
(6 kV, $n = 990 \text{ min}^{-1}$): 2.9%
- full-load loss of the planetary gear
($n_1/n_2 = 990/14.5 \text{ min}^{-1}$): 1.3%

The motor losses thus come to more than double the gear losses. Thus it is urgently necessary to seek a better motor efficiency.

In the case of synchronous motors, the losses can generally be held to a better value by reactive load compensation. But still, other disadvantages have to be accepted.

In any case, it must be determined whether or not the greatest economy has already been achieved for fast running mill motors with large power capacity.

In Figure 11 the basic dependence of motor efficiency on rotating speed and power is represented. The efficiency climbs with decreasing speed and with increasing power.

That means that the motor losses are smaller the higher the speed is, and if instead of two motors each with half the power, one motor with the full power is chosen.

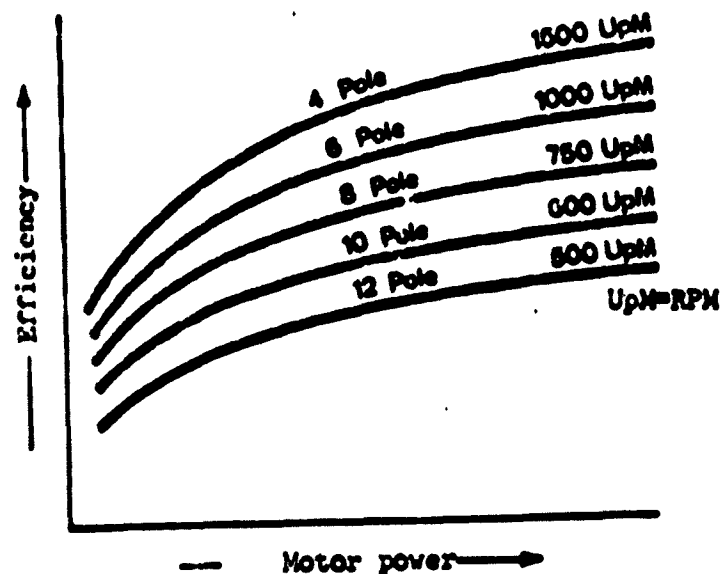


Figure 11: Motor efficiency dependent on rotating speed and capacity.

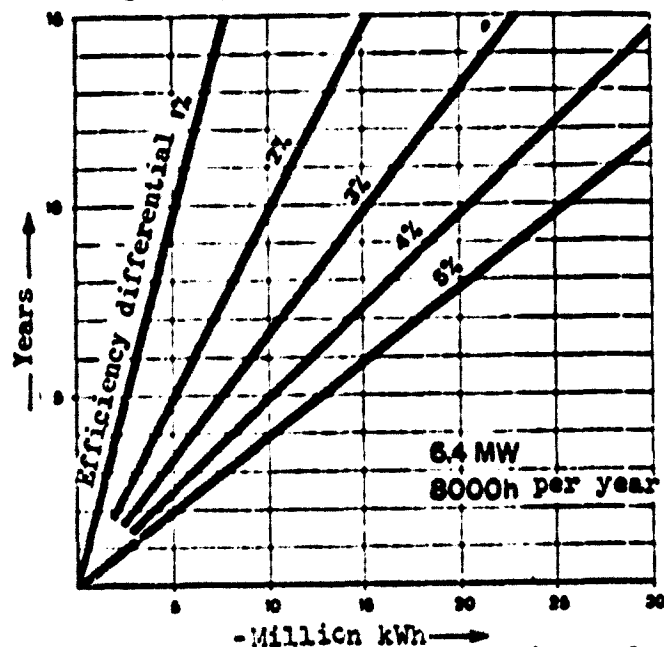


Figure 12: Possible energy saving for the drive of a 6.4 MW tube ball mill by using higher efficiency.

At the same motor power, the machine weight and price decreases with increasing speed.

A higher network voltage, for example 10 kV instead of 6 kV, does not have any effect on efficiency. At higher voltages, the losses are usually larger. Transformer losses occurring by power take-off

from the open net, and injection into the working network, come to about 0.5%, or on that order.

Figure 12 shows the possible energy savings possible by an improved efficiency in the drive system of large mill installations, as seen in the example of a 6.4 MW tube mill.

10. Quality of the Teeth

When judging the quality of the gear teeth, it is important to distinguish:

- material quality and heat treatment
- purpose-determined tooth data
- geometrical manufacturing precision.

The choice of material is based on the solid-end welding behavior on the one hand, and workability and suitability for heat treatment on the other hand.

Decisive significance is attributed to unhindered case hardening, especially of gear parts with large dimensions. For example, the diameter of a planetary gear of an 8,500 HP planetary gear lies in the size range of 1.75 m.

The size of deformations during the hardening process as well as the difficulty of dealing with size alterations which occur while maintaining properties of quality, all increase with the size of the piece being worked on.

Type of gear and operating conditions as well as available possibilities for treatment all have to be considered when determining the nature of the gear teeth.

The actual manufactured quality is largely determined by the

appropriate accuracy values, type and magnitude of special corrections, and by the available treating and test machines.

The basic conditions to be demanded are: constant angular velocity of the teeth which come together under load, and equalized load distribution over the entire flank surface.

The measurement of the precision of the teeth in the case of large pieces places extraordinary demands on the measurement equipment and also demands a considerable amount of time.

The most important checks to be made on the teeth are the individual- and aggregate part error measurements, as well as the profile- and tooth alignment tests.

Figure 13 shows the automatic division measurement device, Maag ES 401, which consists of pick-up and regulation units, with a processing computer.

This electronic testing installation makes it possible automatically to measure the distribution deviations and aggregate distribution deviations on gear wheels of any chosen size, and then to read off the values on a displayed diagram.

Figure 14 shows the testing of an involute profile and the tooth alignment on the central pinion of a planetary gear on a gear wheel testing machine Maag PH-100. This measurement machine has an adjustable basic circle, and is equipped with an electronic measurement- and printing apparatus, which permits a magnification of flaws up to 5000 times.

In general, increased manufacturing quality means higher costs. Thus it largely depends on the proficiency of the manufacturer to create a product by a combination of accumulated

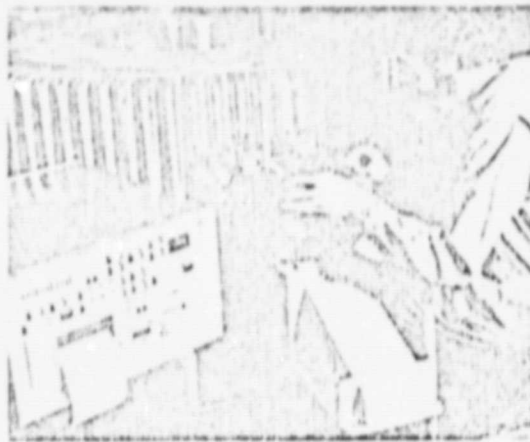


Figure 13: Partial measurement being carried out on the tooth-flank grinding machine using the automatic Maag measurement device.

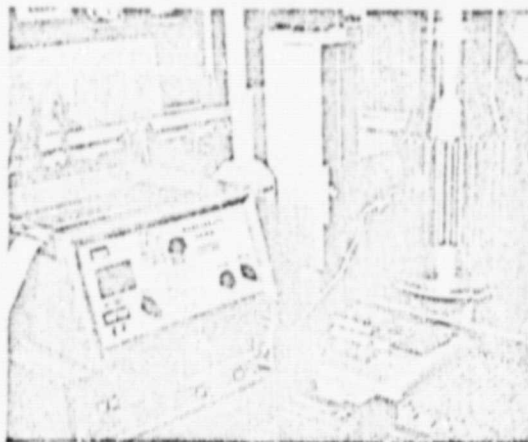


Figure 14: Checking the involute profile and the tooth alignment with the Maag-precision gear wheel testing machine, with 5000-fold magnification of imperfections.

expertise and available means, which will meet the requirements of the cement manufacturing industry from a standpoint of experience and technology, and also provide needed economy.

SUMMARY

Since 1967, planetary gear drives for tube mills have been in operation for a power range of up to 8,500 HP.

This article presents and discusses the operating experience gained during this period. Various values reported serve the installation planner and the operation specialist for the judgment of operational conditions in large tube mills. One reliable method for the measurement of gear efficiency is presented, and possibilities for energy savings in large installations are suggested which can be brought about by better efficiency.

Summary

Heavy-duty planetary gear drives for ball mills have been in operation since 1967. These gear drives transmit up to 8500 HP per installation.

During this period considerable operating experience has been gained and is now being presented and discussed.

Supplementary suggestions regarding the technical and economical connections give an insight into the development achieved considering the plant operator's demands. Various figures are presented, which may be helpful to planning engineers as well as to plant engineers when evaluating main drive conditions. A reliable method to establish the gear-drive efficiency is described, and possible savings of energy due to higher efficiency are indicated.

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